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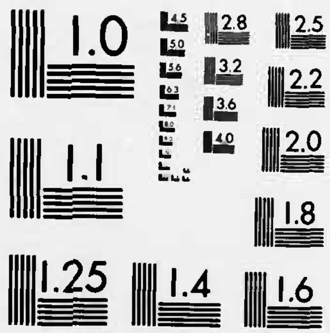

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Technical Memorandum 6-85

THE HUMAN ENGINEERING EYE MOVEMENT MEASUREMENT RESEARCH FACILITY

Joseph Mazurczak
Ramakrishna S. Pillalamarri

April 1985
AMCMS Code 611102.74A0011

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U. S. ARMY HUMAN ENGINEERING LABORATORY
Aberdeen Proving Ground, Maryland

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Visual perception plays a critical role in many tasks the soldier is asked to perform. One key component of these tasks where visual perception is critical is visual search. An example is the acquisition of key information in monitoring displays and directing fire at targets. How should the individual soldier in any given task allocate his attention to optimize performance and what tasks or operator factors affect visual search performance are some of the questions to be answered.

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There is a need for developing a body of data on the principles governing human visual search. This knowledge has direct application to such diverse aspects of the Army's mission as the optimal design of visual information displays in various systems, techniques for intelligent interpretation of reconnaissance photographs, and the design of automatic electronic target acquisition devices.

Driven by this need a system facility has been developed for monitoring eye movement behavior unobtrusively which imposes no mechanical constraints on the subject. The system utilizes the pupil-center/corneal-reflection measurement technique and features a high speed on-line data processing capability. The purpose of this report is to describe the HEL Eye-Movement Research Facility; including the subject viewing studio, the projection room, and the master control room.

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THE HUMAN ENGINEERING EYE MOVEMENT MEASUREMENT RESEARCH FACILITY

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April 1985

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PREFACE

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CONTENTS

THE HUMAN ENGINEERING EYE MOVEMENT MEASUREMENT RESEARCH FACILITY

INTRODUCTION

There are many devices in use for monitoring eye movements (Young & Sheena, 1975). Many of these by their very nature are obtrusive, in that constraints or mechanical attachments are imposed on the subject during actual monitoring of eye movements. We cannot say with any certainty that such constraints compromise or interfere with the normal visual processing. The use of constraints in many measurement systems raises the serious question of the ecological validity of the measurements observed; especially when such studies go on to draw inferences about "natural" visual function. It has been documented that the more obtrusive the instrument used to measure behavior, the higher the probability of obtaining a distorted measure (Wendt, 1938). The continued development and the use of unobtrusive instruments such as the Human Engineering Laboratory (HEL) system can minimize such interference and will further allow a comparison of eye movement data between unobtrusive and obtrusive devices.

This report describes the HEL facility in some detail and its use in studying eye movement behavior. The system described imposes no constraints on the subject that might interfere with comfort or normal viewing behavior; nor is it necessary that the subjects be aware that their eyes are being monitored. Also, the system measures and computes a wide variety of visual responses. These include the display of scan pattern records in real time, the derivation and extraction of fixations and their durations, and the comparative analysis between tasks and subjects. The system has the ability to handle and reduce large volumes of data with an on-line capability that provides immediate feedback to the experimenter.

SYSTEM CONFIGURATION

The HEL Eye Movement Measurement Facility consists of two separate and distinct eye position acquisition systems each with its own subject viewing studio and projection room under the control of one common master control room. One of the eye position acquisition systems is the white light illuminated/dark pupil HEL Oculometer System originally developed by R. H. Lambert which was described previously (see Lambert, Monty, & Hall, 1974; and Monty, 1975). The other eye position acquisition system that is incorporated in the HEL facility is the Applied Science Laboratories (ASL) Eye View Monitor System[1]. This is an infrared (IR) light illuminated/bright pupil system interfaced to the HEL oculometer and data reduction system.

[1]The ASL Eye View Monitor System was developed in support of eye movement research for the U.S. Army Human Engineering Laboratory, Aberdeen Proving Ground, MD, by the Applied Science Laboratories (formerly part of Gulf + Western) under contract DAAG29-83-C0014 from the U.S. Army Research Office.

Either the HEL Oculometer System or the ASL Eye View Monitor System can be the source of real time data display. The selection of the system to be used for data collection depends primarily on the subject population chosen for study and the degree of unobtrusiveness and covertness demanded by the particular experimental questions being investigated. The HEL Oculometer System is completely unobtrusive and covert in that the subject need not be aware that monitoring of eye movements is taking place, but it requires a good pupil/iris contrast for proper eye tracking; whereas the ASL Eye View Monitor System is not dependent on the iris coloration, and thus, can accommodate a larger subject population, but at a sacrifice of some degree of covertness. The IR illuminator can be seen as a dark red circle of light when viewed coaxially.

The HEL Eye Movement Research Facility consists of the subject viewing studio, the projection room, and the master control room. Each one will be described in some detail and how it relates to the total system. The ASL Eye View Monitor System, the calibration procedures used, the data reduction and storage capability, the fixation algorithm used, some examples of systems applications, and finally the limitations and advantages of the system will also be described.

The Subject Viewing Studio

The viewing studio consists of an 8 ft. by 10 ft. acoustically shielded room, an armchair, a stimulus projection screen, and a video camera viewing the stimulus scene. The subject sits in an armchair in front of a rectangular rear projection screen measuring 40 inches on a side horizontally by 24 inches on a side vertically on which a variety of stimulus materials can be presented. Figure 1 shows the subject, seated comfortably in an armchair located approximately 68 inches (1-3/4 m) in front of the plane of the screen, looking at the stimulus field subtending an angle of approximately 30° horizontally and 18° vertically. No physical constraints are imposed on the subject other than that one must remain seated in the chair. A head cushion, which is attached to the headrest of the chair, minimizes neck muscle fatigue during prolonged experimental sessions and also limits excessive head movements. The length of a session ranges between 30 and 50 minutes depending on whether multiple tasks are run consecutively. Generally speaking, as long as the subject's eye remains within the approximate space of a 12-inch cube, the eye movements will be tracked reliably. When tracking is disrupted (e.g., by gross and sudden head movements, gross change in the head position, sneezing, prolonged eye closure, masking, and rubbing of eye by hand), the eye image has to be reacquired manually and brought back into the camera field of view. This procedure normally takes a couple of seconds to complete and depends primarily on operator vigilance and reaction time.

The ASL infrared (IR) system video camera head with its electro-optical tracking elements is located in the projection room directly behind the screen in the area of the black rectangle centered below the stimulus material as shown in Figure 1.

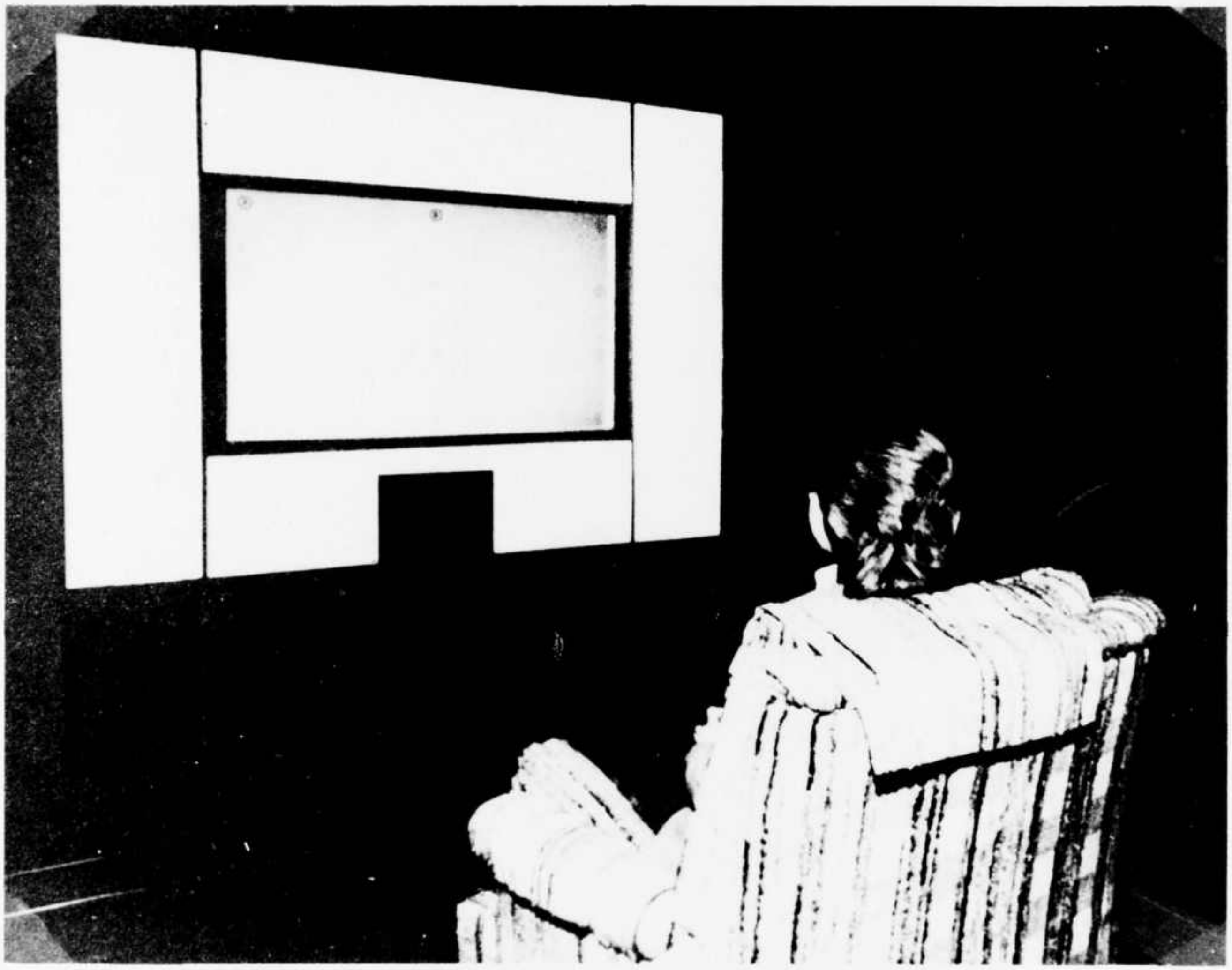

Figure 1. Studio environment showing the subject viewing the calibration scene.

A two-way audio communication system is provided between the experimenter and the subject to monitor verbal responses and to provide instructions from the control room. A handheld pushbutton is used by the subject to mark target detection or task completion. The pushbutton responses are interfaced directly to the computer bus and are recorded automatically.

The studio and stimulus screen illumination are critical to the setup and are set by a compromise of several factors. Among these are density and "busyness" of the slides (stimulus material), as well as consistency between successive slides. The subject stimulus material must be readily viewable and yet sufficiently dark to permit the pupil to remain large enough to be tracked consistently and reliably as the subject scans the entire stimulus field.

The Projection Room

The projection room houses a variety of devices used to project stimulus materials to the subject, such as carousel and random-access projectors, overhead projectors, color video projector, projector lens shutters, filters, and electronic shutter controls. Other image projector devices can be incorporated as needed.

An artist's rendition of the subject and projection room setup is illustrated in Figure 2. The length of the optical path from the subject's eye to the pupil monitoring video camera is approximately 88 inches (2-1/4 m). The optical relay and tracking system, known as the ASL optical head, sits behind the projection screen wall and out of subject view. It consists of all the optics and the tracking mirrors, the IR illuminator, the locating camera, and the IR optimized pupil image camera. Functional representation of the optical head is shown in Figure 3. The optical head is connected, by means of an electrical harness, to the ASL Eye View Monitor System located remotely in the master control room, approximately 25 feet away. All stimulus control functions and pupil acquisition adjustments are handled remotely from the master control room.

The Master Control Room

The master control room, shown in Figure 4, is the heart of the HEL Eye Movement Measurement Research Facility from which control of all the units in the subject and projection rooms is maintained. It contains several minicomputers with their respective system disks, magnetic tape storage devices, and the associated operator consoles which depict real time events signifying experiment operation and the quality of performance of the subject and system. It houses the various hardware interfaces by which all units are tied together and work as a system. The mechanical layout of the various equipment is as shown in Figure 5, and the schematic interconnection of the various units is shown in Figure 6.

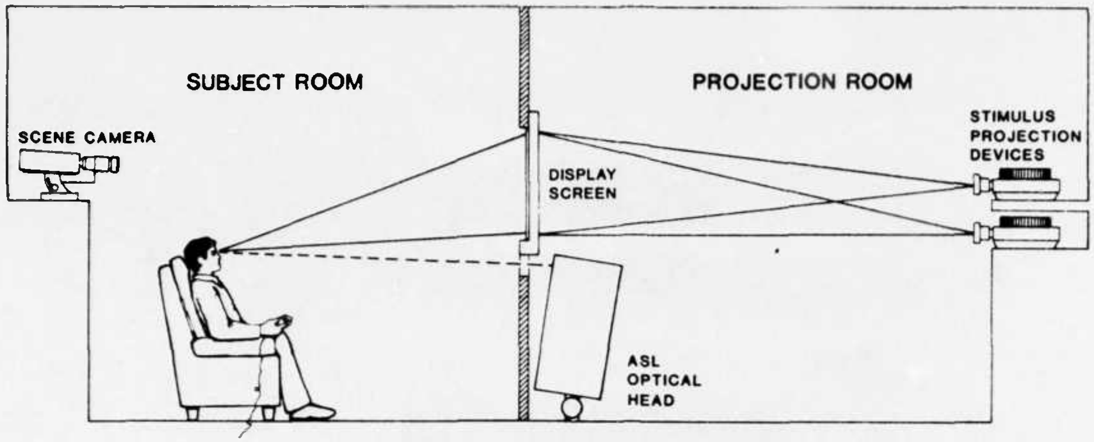

Figure 2. Setup of subject and projection rooms.

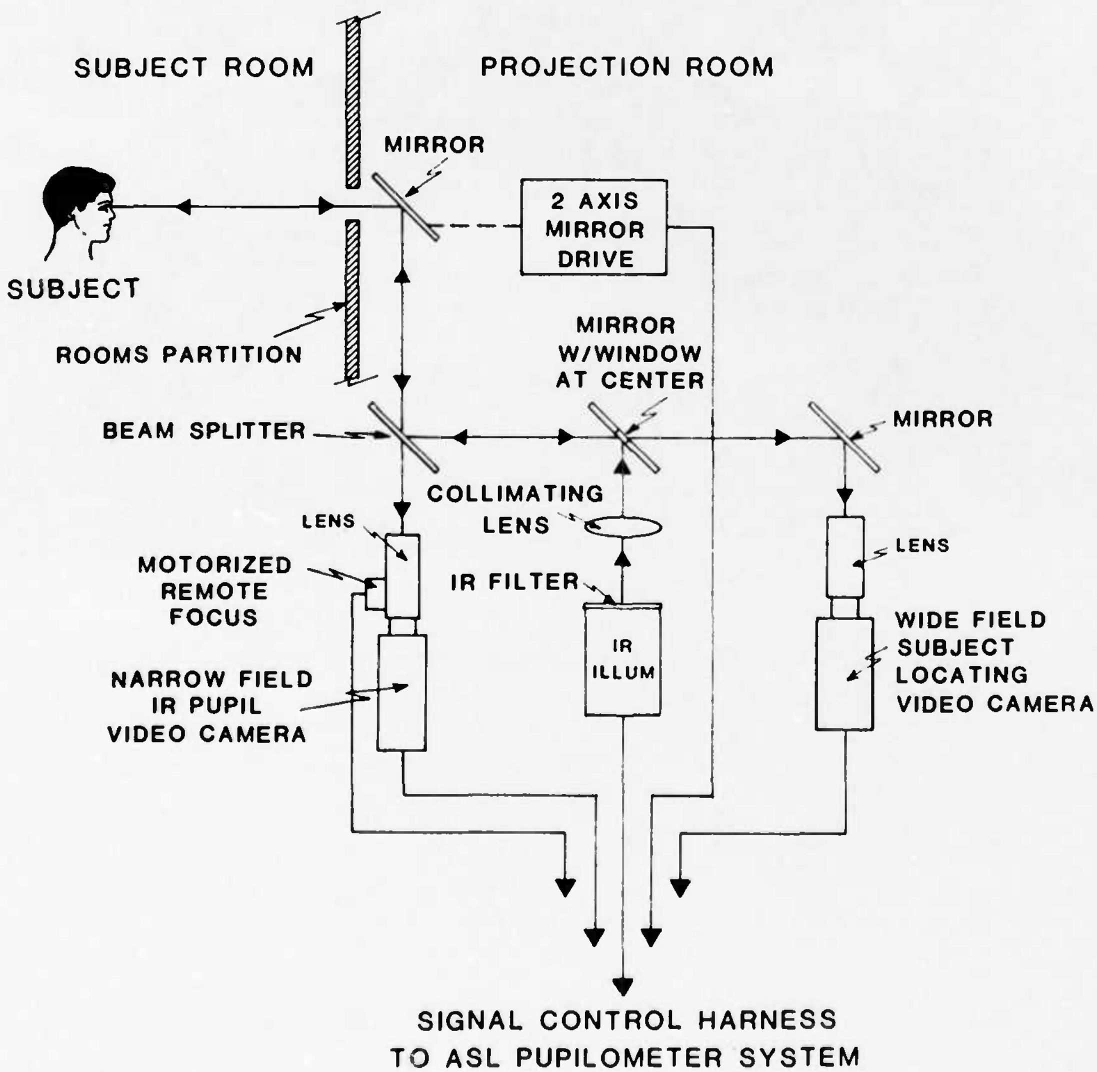

Figure 3. The Applied Science Laboratories (ASL) Optical Head Functional Representation.

Figure 4. The Human Engineering Laboratory (HEL) Eye Movement Measurement Facility Control Room.

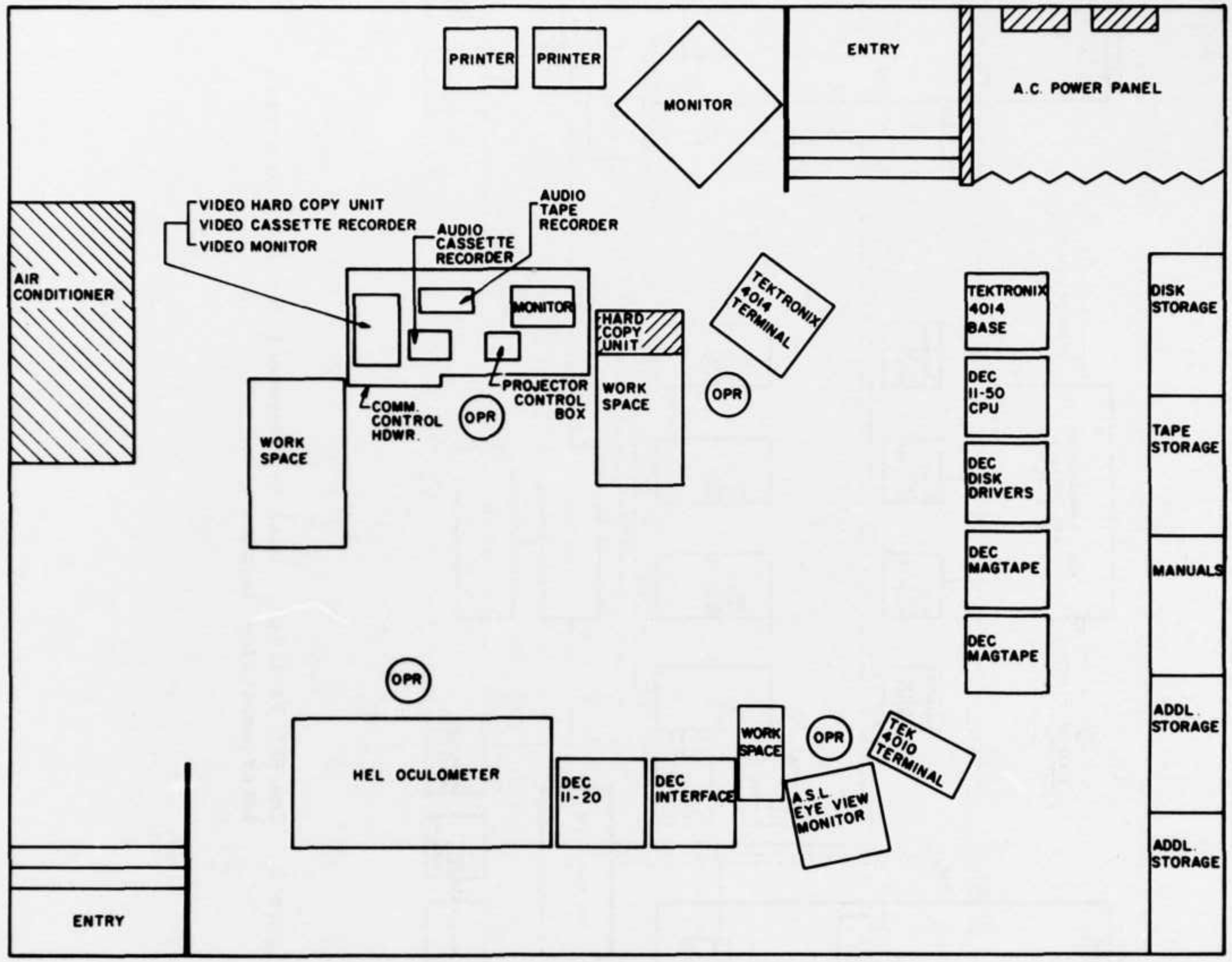

Figure 5. HEL master control room layout.

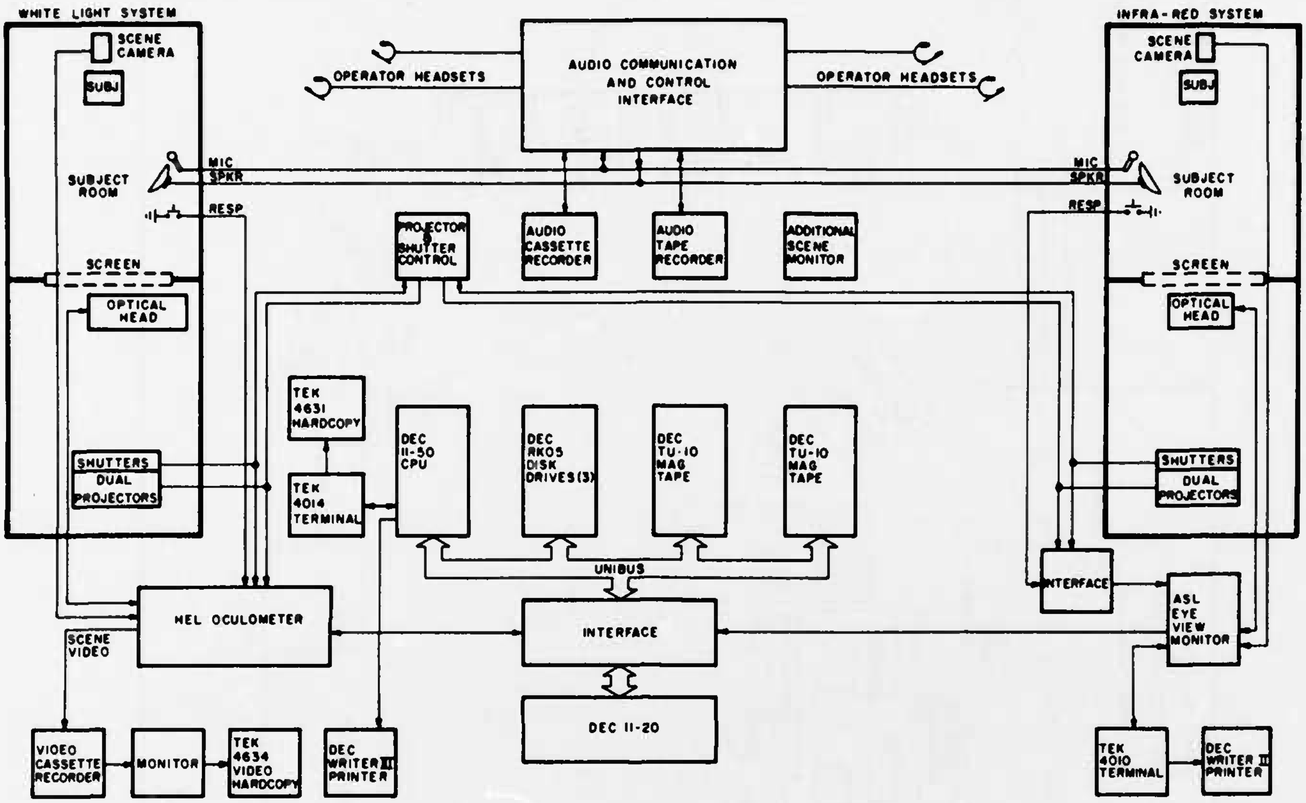

Figure 6. The HEL Facility: Dual Eye-Movement Acquisition System interconnection layout.

The main units comprising the system are the Data Processing and Storage Unit, the Experimenter Console, and the ASL Eye View Monitor System Control Console.

The Data Processing and Storage Unit consists of the Digital Equipment Corporation (DEC) PDP 11-50 minicomputer supported by three disk drives and two industrial grade magnetic tape units running under RT-11 real time operating system. All data concerning the position of the eye; all control flags depicting quality of performance; all shutter, stimulus projector commands, and status cues are routed through this unit for control, processing, and storage. Data is collected at a video rate of 60 fields per second and is displayed in real time so that information, such as the pattern of the points of regard, is provided to the experimenter on a high-speed CRT direct-view storage display terminal (Tektronix Model 4014-1). This information can also be used by the experimenter to change the material being projected based on the subject's previous performance. The minicomputer relays the calibrated data to one of the magnetic tape units for storage and subsequent processing and analysis. The display terminal is also used for calibrating visual response of the the subject, which normally takes about 30 seconds. The procedure will be described later. A hard copy of the scan patterns or processed data, such as average fixation duration or frequency of fixations of a particular stimulus displayed on the CRT storage terminal, can be provided by the Tektronix, Inc., Model 4631 Hard Copy Unit.

The Experimenter Console is dedicated to the experimenter who is in charge of pacing the actual experiment. This includes giving all verbal and taped instructions to the subject, ensuring via a scene monitor that the proper stimulus material is given to the subject, and interrogating the subject and recording verbal responses. The experimenter has charge of the control box which operates the various projection and shutter devices controlling the stimulus material. A scene monitor shows the stimulus material presented to the subject along with a video pointer indicating the subject's point of regard. After calibration, this pointer has direct correspondence with the current point of regard of the subject. This scene with pointer is recorded along with experimenter and subject audio information on a video cassette tape for future reference and analysis. Hard copies of the video frame of interest can be made via Tektronix Video Imaging Unit Model 4634. This provides a permanent record of the stimulus material presented to the subject, which can be used to corroborate and resolve future analytical difficulties.

The ASL Eye View Monitor System Control Console monitors and controls the tracking of the subject's eye while the subject views the stimulus field. It provides the coordinates of the subject's point of gaze, the pupil diameter, and various hardware status flags. This data is routed directly to the Data Processing and Storage Unit data bus for recording and display. The ASL System is provided with a separate magnetic tape unit to serve as a redundant data recording device in case of failure of the main HEL Computer System. Should the HEL System fail during the actual experiment, all data can still be recorded as before and saved for later processing. Because of its complexity, the ASL Eye View Monitor System merits a more detailed description.

The ASL Eye View Monitor System

The ASL Eye View Monitor System consists of the optical head, the optical head control and computation units, the LSI-2/20 CPU and dual 8 inch floppy disk drives made by Computer Automation, Inc., three video display monitors, and additional control and interfacing hardware and software. The system provides video, analog, and digital outputs depicting the eye position and pupil diameter for control, display, and recording on suitable data storage devices. Data recorded on the built-in floppy disk system can be processed either by the integral or an external computer. Short sessions with up to 20 minutes of data can be recorded on each floppy disk. An additional magnetic tape unit is provided for recording data from long experimental sessions. The functional and schematic representation of this system is shown in Figures 7 and 8, respectively. Three video cameras are used to monitor the quality of the eye movement tracking: one provides a view of the scene being presented to the subject, another provides a wide angle view of the subject's head for ease of locating the eye, and the third monitors the subject's pupil. The eye is illuminated by a coaxial near-infrared light source and the image produced is that of a backlighted bright, rather than dark, pupil. Optimal data acquisition requires that the pupil be centered on the "pupil monitor." This is done through the use of the manual tracking control joystick, which controls the position of the motorized mirrors in the optical head. The monitors serve as visual indicators for the operator as to what is being acquired and the quality of tracking.

By observing the quality of the bright pupil image, the operator makes appropriate adjustments to provide optimum tracking performance under the established experimental conditions. This is accomplished through motorized focus and manual or auto head tracking control. Next, the threshold of the pupil discriminator and the corneal reflection discriminator are each set for reliable detection of the pupil and the corneal reflections. When this is done correctly, a cross-hair will depict the center of each as shown in Figure 7 on a display labelled the "pupil monitor." The subject's eye rotation (as opposed to eyeball translation resulting from head motion) and consequently the point of gaze is determined by the measurement of the center of the pupil with respect to the center of the corneal reflection. These two features move together with head position, but differentially with eye rotation. The video detection and coordinate extraction technique depicting the eye's point of gaze is described in detail by Sheena (1975).

As long as the eye image remains within the center of the field of view, the measured eye position, for all practical purposes, is independent of the head position. The system tolerates limited head motion, talking, etc., without the need for recalibration. Position information, representing the point of gaze of the subject, is presented on a video monitor by a cross-hair marker superimposed on a picture of a scene being viewed by the subject.

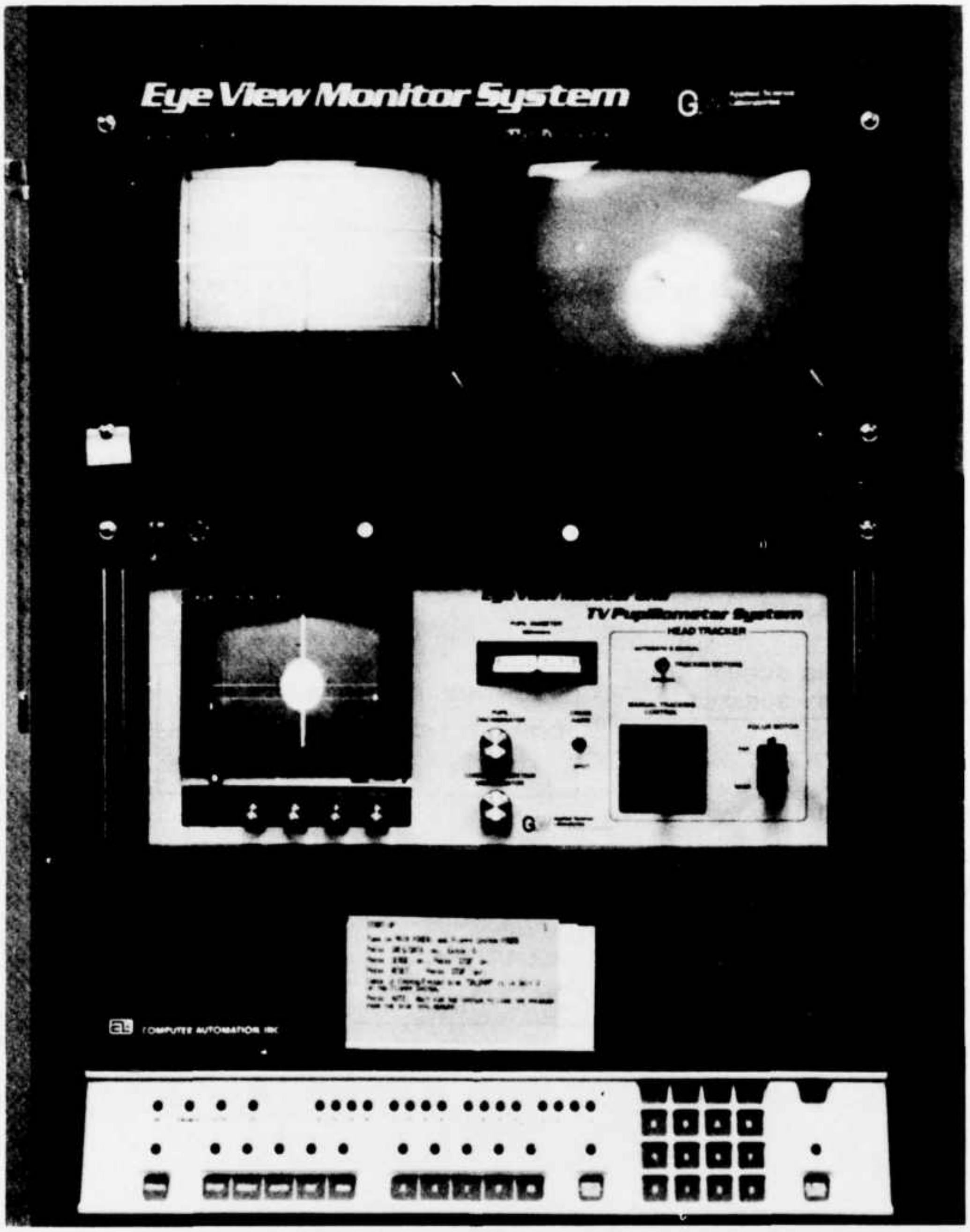

Figure 7. ASL Eye View Monitor System.

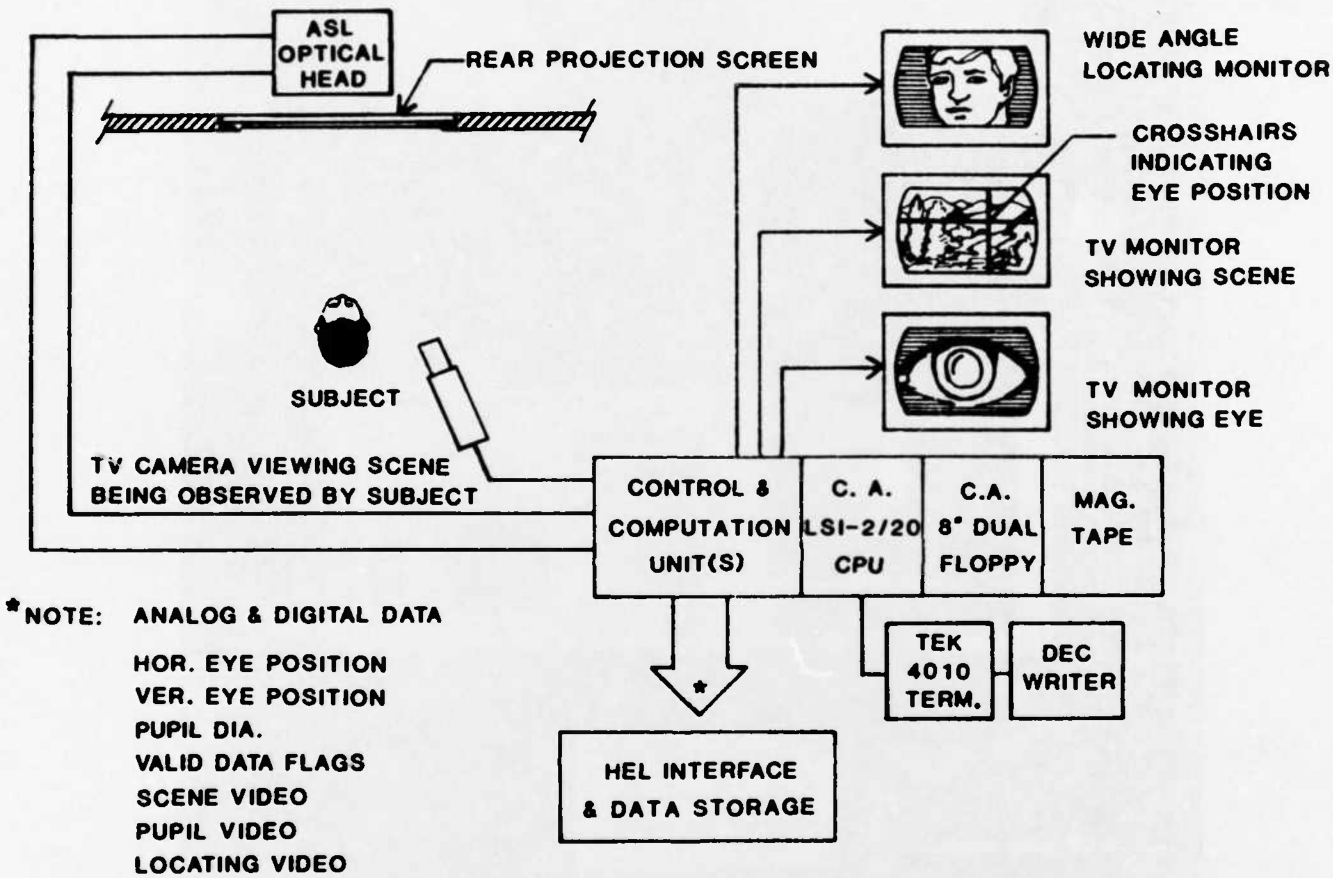

Figure 8. Schematic representation of the ASL Eye View Monitor Acquisition System.

By using real time software processing capability and special recognition circuitry, the system is able to recognize the pupil and the corneal reflection to the exclusion of other artifacts such as eyelids, eyelashes, some eyelid truncation, noise, glasses, etc., thereby reducing operator intervention with changing experimental conditions. The system works best with pupil diameter of 3 mm or larger.

Since this equipment is interfaced directly to the HEL Data Processing and Storage Unit, a standard HEL System calibration procedure is followed and described below. The ASL Eye View Monitor System has the capability of being used as a stand alone system and this mode is used as a back-up when the HEL System has failed and experiments must continue. This separate calibration procedure is described in the appendix.

The System Calibration

An effective technique has been developed to gather calibration data without the subjects being alerted to the fact that their eye movements are being monitored. The calibration procedure is embedded and made part of the experimental task context. The subject is asked to view a series of calibration points as shown in Figure 9a (12 points in this case viewed in any sequence). Some questions may be asked about the number and color of dots surrounding each calibration point which causes the subject to fixate on each point for a period of time. As a result, a cluster of points representing the individual eye positions are accumulated on a direct view storage display terminal (Tektronix 4014-1), as shown in Figure 9b.

The console operator viewing the accumulation of points can signal the experimenter to re-direct the subject to any one of the calibration points without disruption of the calibration process or subject attention, if for some reason there may not be enough points in the cluster to facilitate good calibration. Normally, this is not necessary, unless there is gross movement on the part of subject causing the system to track poorly.

With sufficient points accumulated on the storage terminal, and while the subject's attention is being directed to the next stimulus slide, the console operator enters instructions to the computer to complete the calibration process. This is done by placing a cross-hair over the estimated mean position of each cluster of the accumulated target points, as shown in Figure 9c, and takes approximately 30 seconds. The computer performs the necessary mathematical transformations and maps the raw eye position into the stimulus scene. Using Quadratic terms in the mapping model for the X and Y eye position with additional crosstalk correction terms is sufficient for this mapping transformation and the resultant display is updated as shown in Figure 9d. Now, this display bears a one-to-one correspondence to the actual visual scene. Each horizontal and vertical marker represents 1.5 degrees of the visual angle. Using the ASL Monitoring System, a consistent eye position accuracy of better than 1 degree has been demonstrated.

Figure 9a.

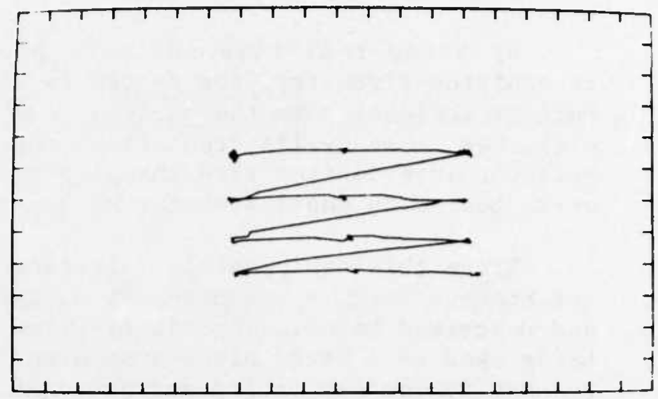

Figure 9b.

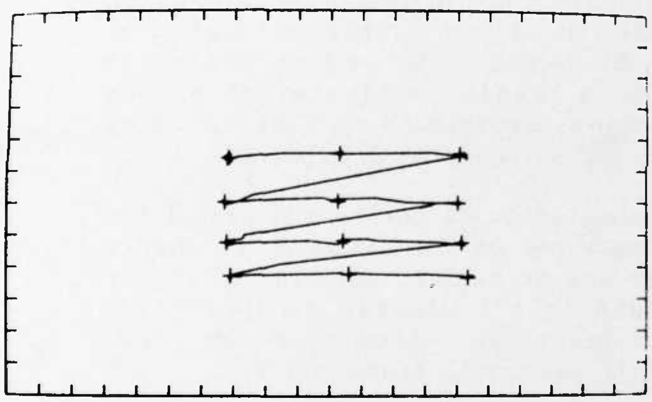

Figure 9c.

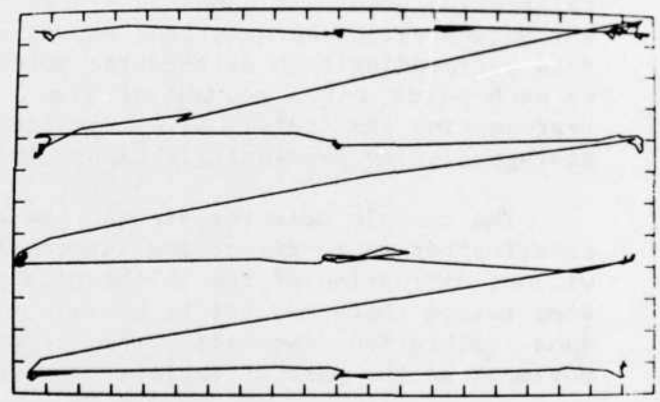

Figure 9d.

Figure 9. These series of figures represent the HEL calibration sequence. Subject views the calibration scene (a) composed of 12 points, each consisting of a number (or a letter) surrounded by multicolored dot cluster. The resulting pattern (b) on the storage terminal is calibrated by placing cross-hairs as shown in (c) at each fixation cluster. Computer reformats the display and subject is instructed to view a similar slide, resulting in stimulus scene being fully calibrated, as in (d), where visual stimulus field of 30° by 18° is represented, with each marker corresponding to 1.5 degrees of the visual angle.

VISUAL SEARCH EXAMPLES

Once the system is calibrated, the experiment continues and the calibrated data is written on magnetic tape. A real time display of the subject's visual activity is "painted" on the storage terminal. This represents the accumulated points of regard as the subject performs the various visual tasks that have been assigned. A hard copy of this accumulated activity can be obtained at any time for reference and indication of performance.

An example of a typical search task to find a hidden target taken from a recent set of search experiments is shown in Figure 10a. This stimulus slide consists of "S" and "10" texture pairs developed by Julesz (see Julesz, 1980, for detailed discussion). It shows a triangle composed of three 10's in a field of randomly perturbed S's, illustrated by a broken circle. Figure 10b represents the resulting scan pattern as the subject searches for the target on the stimulus slide, locating it at the lower right hand portion of the figure, represented by the cluster of short lines. Another target scan is depicted in Figure 10c with target found cluster of 10's, shown at the upper left of figure. Figure 10d serves as an aid to the experimenter and illustrates what the experimenter sees on a video monitor as the subject views this stimulus scene. The video cross-hair superimposed over this scene depicts the subject's eye position when the target is found, as illustrated by the solid circle.

The cross-hair indicating the on-going position of the subject's point of gaze is a very useful feature for subjectively judging the performance of both the subject and the system. It is superimposed over the visual scene and recorded on video magnetic tape with the corresponding ongoing voice record of experimenter's instructions and subject's responses for future reference. Hard copies of this tagged visual scene can be made through the use of a video copy unit.

DATA PROCESSING CAPABILITY

Calibrated position data, which incorporates the various shutter cues, projector timing cues, and subject response cues, is recorded on the 9-channel magnetic tape unit using a custom assembly program to conserve time and tape space. Data from approximately 10 subjects, consisting of 3 or 4 tasks, lasting 30-50 minutes total time for each subject, can be collected on one tape. Experiments consisting of approximately 60 to 80 usable subjects are the usual requirement in our studies.

Once the experiments are completed, the calibrated data is processed, all subjects with common tasks are selected, and a new task file is created for each task, using a second magnetic tape unit. The purpose of the new task file is to extract only the pertinent data meaningful to the experimental task with its associated start/stop and slide/shutter and response cues. This results in data of a more concise and compact form with the ability to record common tasks of all subjects onto one tape and thus eliminate all data non-essential and not meaningful to the task; e.g., data collected between the visual stimuli, etc.

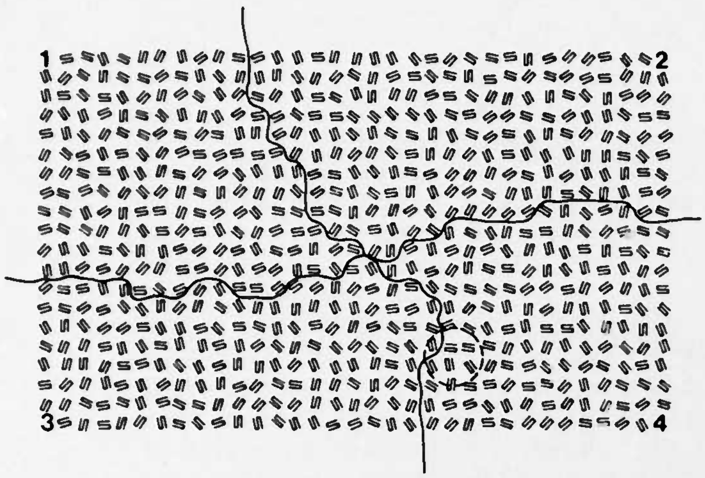

Figure 10a.

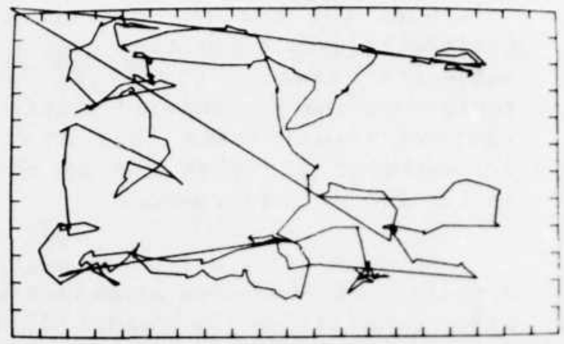

Figure 10b.

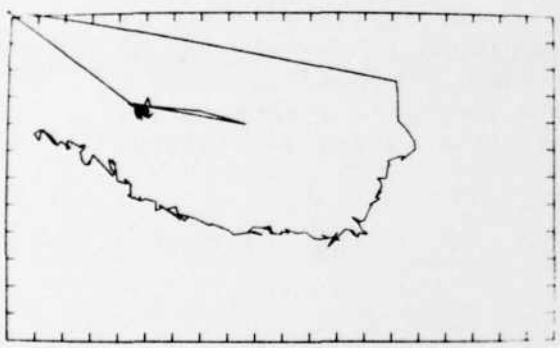

Figure 10c.

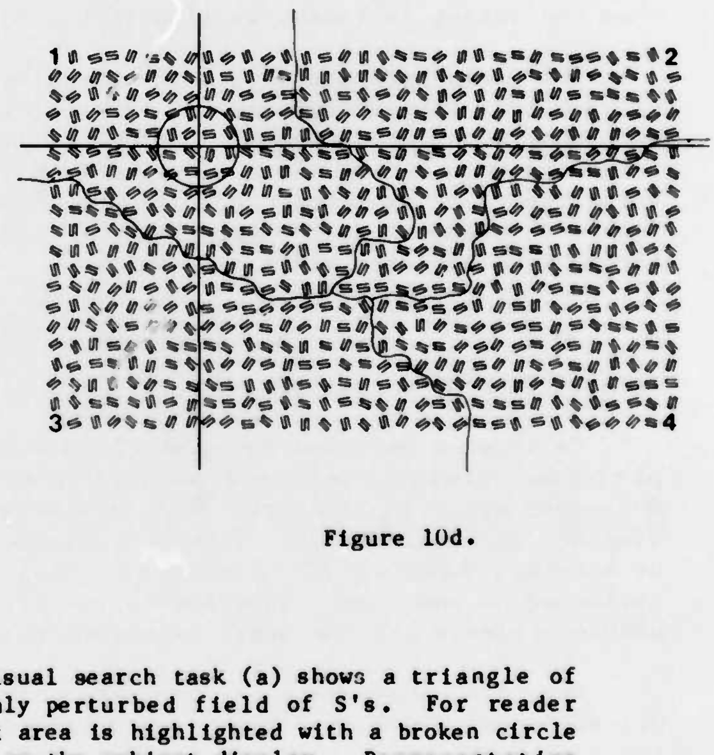

Figure 10d.

Figure 10. Typical target in a visual search task (a) shows a triangle of three 10's in a randomly perturbed field of S's. For reader convenience the target area is highlighted with a broken circle which does not appear on the subject display. Representative search behavior is shown in (b) with the target found (note the fixation cluster at the lower right). Similar target scan in (c) with target in upper left is also tagged by white cross-hair lines showing the position of detected target in (d).

Once the task files are built, they are reprocessed separately using batch mode processing to create a fixation and a summary file for each task. These files are then stored on hard disk and are the primary source from which all data bases for statistical and mathematical analyses are derived. Data on this medium lends itself more readily for processing and for plotting graphs of histograms, various cluster analyses, and detailed running time sequences of fixations in developing the scan record of the scene. Capability exists for the transformation of fixation display, indices of calibration offset, rotation, and repositioning of fixation display for superposing over scene pattern.

The fixation file and the summary file are used for the fixation extraction. These serve as a summary of all fixations on a particular stimulus slide. Everything else is derived from these two files. Plots of fixations depicted by circles with the duration of these fixations directly proportional to the diameter of the circle are very useful indices of visual behavior. Strip-chart record plots of video field versus the X-position and the Y-position are also available. These can be used as an indication of where a fixation starts and stops and as an accuracy check of the fixation algorithm. Figures 11a through 11d illustrate examples of cumulative X-Y plots of eye position data, extracted fixation plots, strip-chart records of X and Y positions, and extracted fixations plotted in strip-chart mode. Each of these plots references the same data window. Since the fixation is the most commonly used measure of eye-movement behavior, the algorithm used defining it merits separate discussion and it is covered briefly.

DEFINING A FIXATION

The basic data consists of the calibrated X and Y positions of the point of regard of the eye upon the stimulus scene. The system used to gather this data is restricted to the acquisition sampling rate of 60 data points per second by the use of standard TV equipment format. The fixation and its time history is the most common method of defining eye movement behavior. Conceptually, a fixation is simply the intersaccade time during which the eye is relatively stationary. The fixation algorithm used at the HEL facility was originally developed by Lambert (see Lambert, Monty, & Hall, 1974). A detailed description of the algorithm used is given in an article by Karsh and Breitenbach (1983).

Briefly, the algorithm defining a fixation operates as a complex software filter which determines first, whether each field sample is usable (e.g., contains valid information to determine the eye position); and second, whether a sufficient number of fields are within the boundary conditions used to define a fixation. The shortest time used to define a fixation is 100 msec or six TV fields (6/60th sec).

Data of a particular field sample may be considered unusable if the subject looked away from the scene field of view, eye blinks, gross head movements, coughing, sneezing or laughing, and other factors which may mask the pupil or corneal reflection. Data is also lost during the time necessary to re-acquire the pupil image manually as a result of any of the above mentioned artifacts.

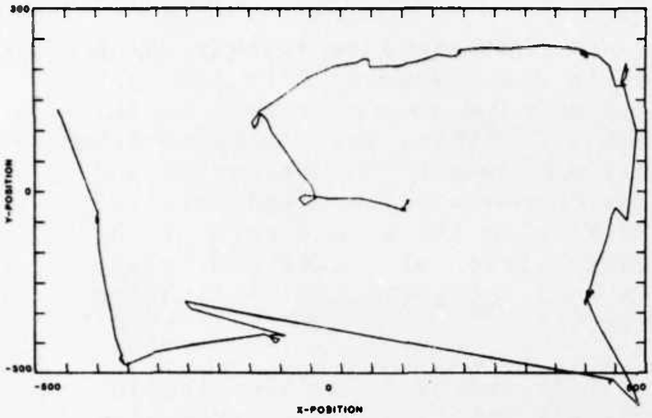

Figure 11a.

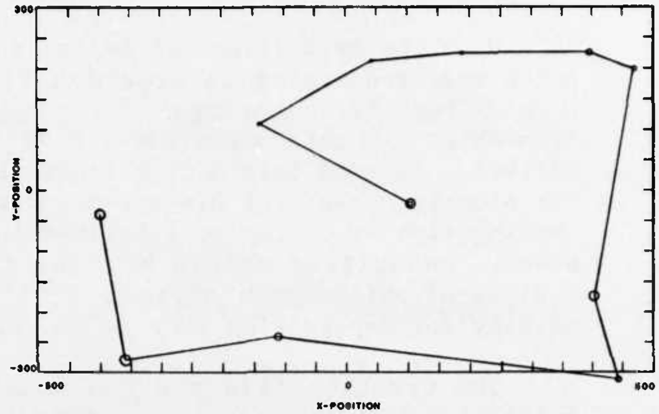

Figure 11b.

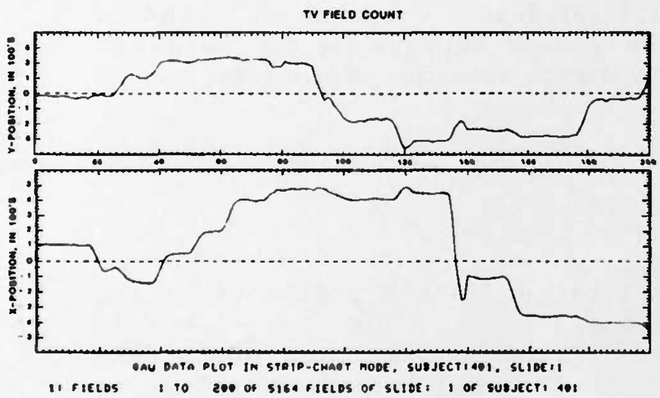

Figure 11c.

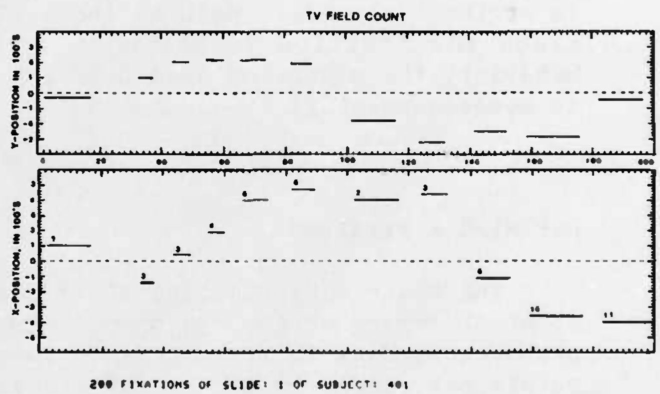

Figure 11d.

Figure 11. Illustrative plots of data reduction capability: (a) X-Y plot of eye position data, as obtained in real time. (b) Scan path record of fixations obtained when the data is processed using the fixation algorithm. The circle size represents the duration of each fixation. The double circle represents the starting point of the scan path. (c) Eye position data showing Y-position (top) and X-position (bottom) versus TV field count, in strip-chart mode. The gaps represent data loss. (d) Fixation position versus TV field count in strip-chart mode. The duration of each fixation and the inter-fixation gaps (mostly saccade related) can be seen here.

SYSTEM ADVANTAGES AND LIMITATIONS

The advantages of the HEL facility are that the subject's head is not required to be mechanically constrained, and the system does not interfere with or restrict the subject's visual behavior. Neither the tracking device nor the experimenter is visually apparent to the subject. It is unnecessary to call the subject's attention to the fact that their eye movements are of interest and are being monitored and recorded, thus avoiding self-consciousness of the subject. Even the calibration task given each new subject is integrated into the context of the experimental tasks. Each fixation can be identified by location and duration so that progressive and regressive saccades are easily discernible. Fixation scan patterns can easily be overlaid over the stimulus scene for subject performance assessment of each task. The system can handle voluminous quantities of data in real time and has extensive data reduction capability off-line, both of which can be handled with ease and speed.

The main limitation is the system's monitoring accuracy which is a direct result of not restraining the subject's head movements in any dimension. Currently, the system has demonstrated approximately 1 degree of position accuracy, but this could probably be improved further with more sensitive image sensors and improved optics of greater magnification and light gathering efficiency. Solutions for improved accuracy are well within the state-of-the-art and are currently under development.

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APPENDIX

ASL EYE VIEW MONITOR CALIBRATION WHEN USED AS A STAND-ALONE SYSTEM

ASL EYE VIEW MONITOR CALIBRATION WHEN USED AS A STAND-ALONE SYSTEM

Before the full ASL System calibration is attempted using a real subject, mapping of the scene field must first be done to store the actual calibration points in the central processing unit (CPU) memory. A calibration slide is used with a set of target points (nine in this case) distributed in the scene area using a 3 by 3 matrix. Looking at this matrix on the scene monitor, the operator activates the horizontal position target sweep mode, seen as a bright vertical line moving from left to right superimposed on the scene video raster. Then, the sweep is stopped at each target point, where the CPU reads and stores that point's X-position. The sweep is reactivated again and stopped at the next position, and this procedure is repeated until the X-position of all points has been stored in memory. This is done similarly for the Y-position of all target points, except that the vertical sweep mode is seen as a bright horizontal line moving from top to the bottom of the scene video raster. The X-Y coordinates of all the nine points are thus stored permanently in the CPU memory and do not have to be re-entered unless the physical position of the optical head or the scene camera have been disturbed.

Once these points are stored in the system, it is ready for subject calibration. While viewing the same calibration slide, the subject is instructed to look at the target points in sequence. Allowing for the eye to settle down at each point, a button is pressed to acquire the instantaneous eye position at that point. After the last target point has been acquired, the computer performs the necessary mathematical transformations and maps the raw eye position into the stimulus scene. Use of Quadratic terms in the mapping model for the X and Y eye position with additional crosstalk and corner correction terms is sufficient for this mapping transformation. Correctional factors for head motion and tracking mirror motion compensation terms are also added and are intended to be subject independent. For detailed treatment of the eye position to scene mapping transformation, the reader is referred to the report given by Sheena and Borah (1981). The calibration process is completed and for all practical purposes the instrument is calibrated almost as soon as the last target point is fixated by the subject. However, this procedure fails when one or more of the target points has to be re-entered because of a subject's sudden head movement or eye blinks at the instant a point was acquired and found to be missing or out of line with the rest of the calibration points. There is a provision to recalibrate any or all points, but this results in increased calibration time, and special instructions must be given to the subject to fixate on these points again.

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